Life Cycle Assessment of Grid Tied SHSs in Bangladesh with Respect to Conventional Sources

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Abstract— **In this work life cycle assessment of grid-tied solar PV (Photo Voltaic) systems is studied to test their feasibility in regions of Bangladesh, where grid is not sufficient enough to fulfil the demand of mass people. Economic performance of renewable power sources and non – renewable fuel supplied generators (nine Walton generators powered by petrol and one Walton generator powered by diesel) are investigated and compared in terms of net present value analysis. The analysis suggests that grid-tied PV systems are better both economically and environmentally from the context of a developing country like Bangladesh. Moreover, the results establish the finding that the choice between renewable or traditional power sources from an economic point of view depends on the load demand of the customers and the power rating of the generators.**

Index Term— **Grid tied, LCC, ALCC, Solar PV, conventional sources.**

I. Introduction

At the present time the electricity companies of Bangladesh are unable to produce enough electricity to meet the domestic, industrial and development needs. The generation capacity is about 8005MW (as on March 2012) and maximum demand served so far is 6066 MW (March 22, 2012) [1] whereas the total demand is 9023MW [2]. According to USAID, the demand for energy is growing at a rate of 10% annually. In 1971, 3% of the total population in Bangladesh had access to electricity. Today, approximately 33% of the population has access, which is also low compared to many developing countries [3]. This crisis is partly due to over-dependence on gas. It fulfils more than 70% of energy needs. The present gas deficit against the national demand on a daily basis is expected to increase further in the upcoming future. The crisis will deepen unless a greater share of indigenous coal is included in the energy mix [4].

But burning fossil fuels emits carbon di oxide, nitrogen oxide, sulphur dioxide and other toxic metals into our atmosphere, directly causing increasing incidents of lung disease, polluting soils and waters, damaging crops. Bangladesh is one of those countries where carbon emission is increasing day by day and for the sake of creating more power by using the limited fossil fuel would make the situation worse.

In this situation, stronger emphasis is required on efficient utilization of renewable energy sources like wind, biomass, solar and hydropower. As Bangladesh is made up with mostly flat landmasses, potential of hydropower generation is low for the country. Installment of wind-powered generators is still in the premature stage mainly because of seasonal variation of wind forces and long distance between potential sites for windmills and major grid lines [5]. Biomass can be a promising alternative but still requires a lot of economic assessment and development of infrastructure before it can become a feasible source for power. In such a scenario solar power is considered to be the most promising alternative source of energy for Bangladesh. Average monthly solar irradiation available in Bangladesh is 4-5 kWh/m^2 which is indeed a good indication of the potential for solar energy [6].

The SHS (Solar Home System) distribution agenda in Bangladesh is considered to be one of the most efficacious of its kind in the world, bringing power to rural areas where grid electricity supply is neither available nor expected in the medium term [7]. Solar electricity can be used in cities too where grid connection is available as the electricity companies of Bangladesh are insufficient to ensure 24/7 electricity. Load shedding for almost six to ten hours a day in the grid-connected areas has become a usual phenomenon [8]. In the FY 2010, load shedding was imposed on 354 days [9] and in FY 2011 the deficiency of power was about 1335 MW [10], which is a very alarming state.

In spite of the benefits of renewable energy, the economic feasibility of solar power is often put into question due to the large investment cost associated with it. But it is easy to overlook the fact that solar PV systems do not incur regular fuel costs like diesel or petrol generators. Moreover, PV systems also require less maintenance than fossil fuel powered generators and hence incur lower operational cost. Another benefit of solar PV systems is the reduced GHG (Green House Gas) emission, which make them environment friendly. At first glance, it may appear that diesel or petrol generators are better options than solar PV units from an economic point of view. But to compare the true economic worth of solar power and fossil fuels, conventional appraisal techniques will not be effective due to their different cost structures. Life Cycle Cost Analysis (LCCA) has proved to be a more reliable method in this regard [11]. In this paper, LCCA method is applied to evaluate the lifetime performance of grid-tied solar systems and fuel generators from the context of Bangladesh and it is found that the choice between renewable or traditional power sources depends to a great extent on the load demand and the power rating of the source.

II. Theory of Life Cycle Cost Analysis

LCCA covers the total cost of a power source in three phases: construction phase, operational phase and decommissioning phase. The construction phase includes the initial investment cost.

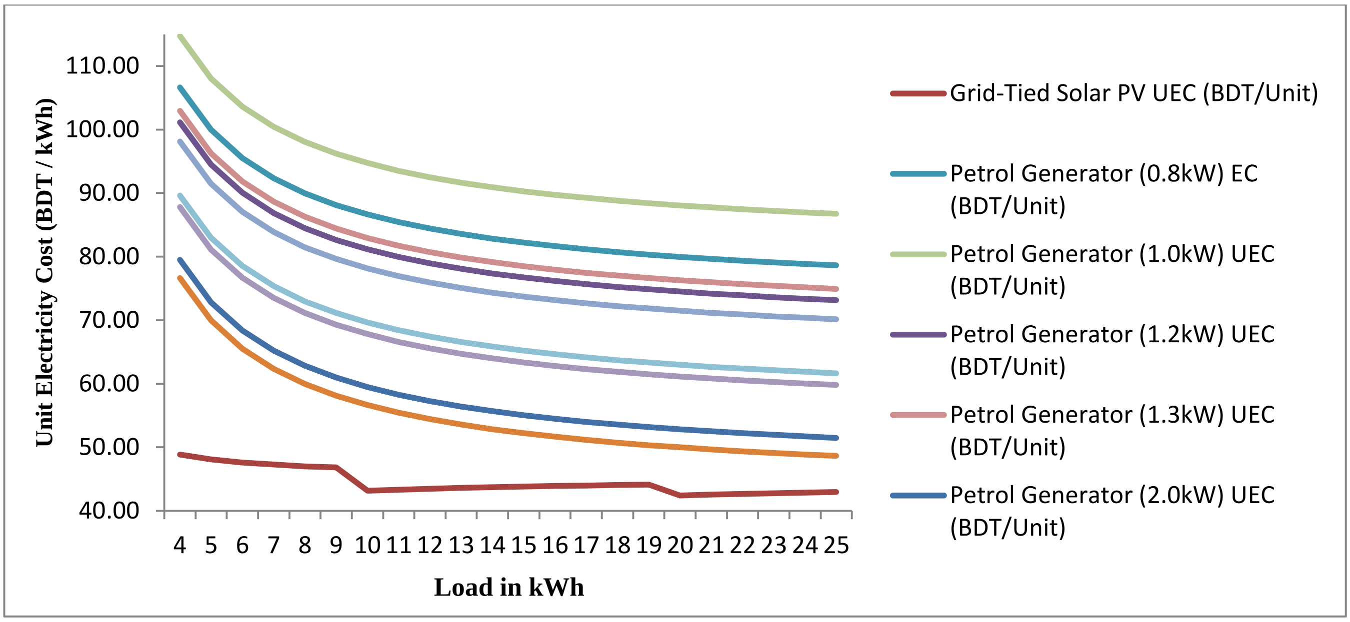

Fig. 1. Comparison of Unit Electricity Cost between Grid – Tied Solar PV & Petrol Generators

Operational phase contains the fuel cost and the cost incurred due to operation and maintenance. The decommissioning phase covers the cost related to termination of the project and disposal of the equipment. All these costs are summed up to provide the total life cycle cost of the project. The overall cost incurred over the lifetime is then converted into unit cost per kWh of energy [11]. This approach has gained popularity among the researchers and been followed in a number of research projects related to energy production.

1) Net Present Value (NPV): As Life Cycle Cost Analysis comprises not only the initial cost of a project but also all future costs for the entire operation of a system, the Net Present Value (NPV) of the components has to be taken into account to make a meaningful comparison. For this reason, all future costs are discounted in LCCA to their equivalent value in the present economy and the present worth of the costs is calculated. Thus the LCC analysis takes into account the changing value of money as well as cost escalations due to inflation.

2) Overall System Cost: The overall system cost associated with a power system operating for a number of years can be classified into three branches. The first classification is the initial capital cost of purchasing equipment that includes cost of PV modules and wiring For a PV system. In case of diesel or petrol generator based power system the capital cost comprises of paying for generator, circuit breaker and other equipment and installation cost. Secondly, recurring costs that occur every year of operation are primarily due to maintenance of equipment, site and overall system supervision. In case of generator-based system, the generator is checked at regular intervals whether it requires overhauling. In a PV system the batteries require inspection and topping up at about three month's interval. Finally non-recurring costs are those that occur on an irregular basis. The expenditure of replacement of major components of a system like battery or other equipment is referred as non-recurring or single payment cost.

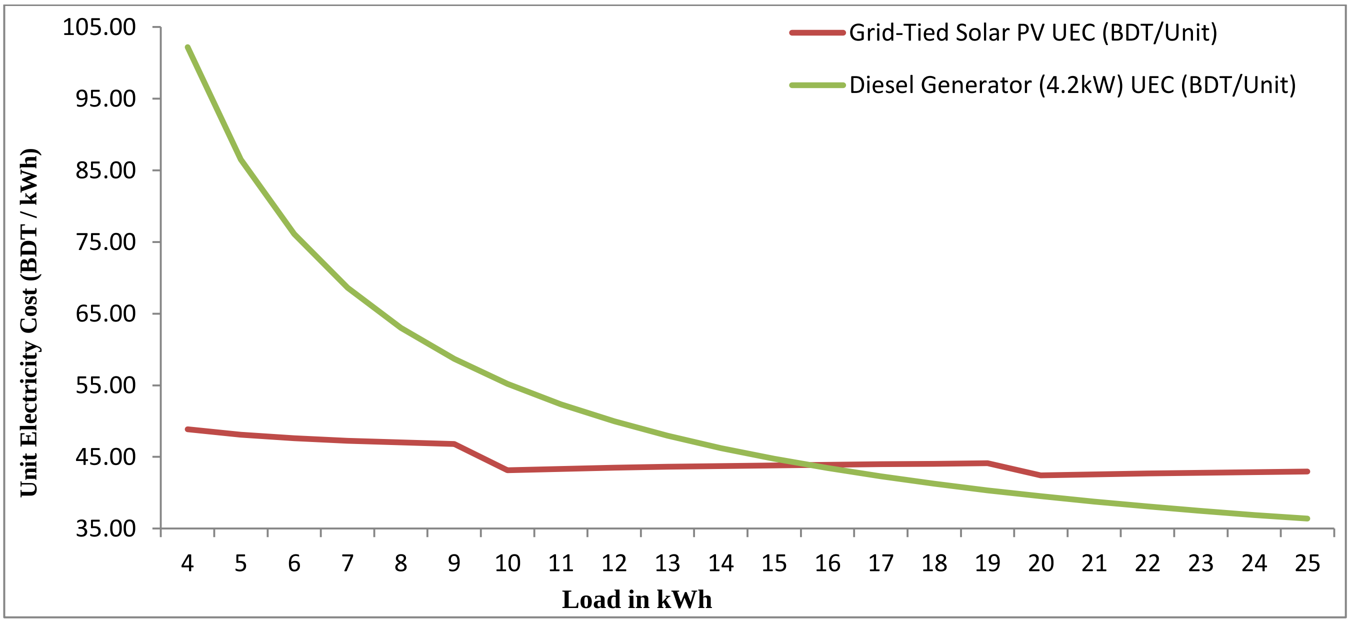

Fig. 2. Comparison of Unit Electricity Cost between Grid – Tied Solar PV & Diesel Generator

3) Economic Factors: A number of economic factors have to be taken into account while calculating the life cycle cost. The period of analysis is the lifetime of the longest-living system under comparison. In case of PV system the lifetime is about 20 years and for petrol generator the lifetime is about 5 years [12]. So, for LCC analysis the period is taken to be 20 years. As the components and services get expensive over time, the excess inflation factor takes into account this cost escalation. In this calculation inflation factor is applied to fuel cost and other maintenance and replacement costs. The last factor is the discount rate which is the rate at which money would increase in value if it was invested in other projects rather than in power system.

TABLE I
ASSESSMENT OF SIZE OF GRID TIED SOLAR PV SYSTEM COMPONENTS

Daily Load kWh	Solar Panel	Inverter
3kW×2h = 6kWh	$\frac{6000}{5.24\times0.8\times266.4} \approx 6$ modules	$\frac{6000}{5.24\times0.8\times0.92}$ = 1555.76W
3kW×3h = 9kWh	$\frac{9000}{5.24\times0.8\times266.4} \approx 9$ modules	$\frac{9000}{5.24\times0.8\times0.92}$ = 2333.64W
3kW×4h = 12kWh	$\frac{12000}{5.24\times0.8\times266.4} \approx 11$ modules	$\frac{12000}{5.24\times0.8\times0.92}$ = 3111.52W

4) Calculating LCC and Unit Electricity Cost:: For the calculation of LCC at first the total net present worth of recurring and non-recurring cost has to be calculated. To do this, the future cost is multiplied by a factor to incorporate the inflation and discount rate. For a non-recurring single future cost Cr, paid after N years, the present worth (PW) is given by [13]

$$PW = Cr \times Pr = Cr \times \left(\frac{1+i}{1+d}\right)^N \ldots\ldots\ldots\ldots (1)$$

For a recurring payment Ca, which occurs annually for a period of N years, the present worth (PW) is

$$PW = Ca \times Pa = Ca \times \left(\frac{\left(\frac{1+i}{1+d}\right)\left(\left|\frac{1+i}{1+d}\right|^N - 1\right)}{\left(\frac{1+i}{1+d} - 1\right)}\right) \ldots\ldots\ldots\ldots (2)$$

Here Pr and Pa are the present worth factors for non-recurring and recurring costs respectively. Pa is called the Annualization Factor. Here the present worth factors for non-recurring and recurring costs are

$$Pr = \left(\frac{1+i}{1+d}\right)^N \ldots\ldots\ldots\ldots (3)$$

$$Pa = \left(\frac{\left(\frac{1+i}{1+d}\right)\left(\left|\frac{1+i}{1+d}\right|^N - 1\right)}{\left(\frac{1+i}{1+d} - 1\right)}\right) \ldots\ldots\ldots\ldots (4)$$

The sum of individual present worth expenses (PW), calculated from eqn. (1) and (2), gives the total life cycle cost of the system. From the overall life cycle cost the annualized life cycle cost (ALCC) and unit electricity cost (UEC) are calculated using the annualization factor (AF) and daily load (DL) using

$$ALCC = \frac{LCC}{AF} \ldots\ldots\ldots\ldots (5)$$

$$UEC = \frac{ALCC}{DL \times 365} \ldots\ldots\ldots\ldots (6)$$

According to the above discussion, life cycle cost analysis has been done for the grid tied SHSs and conventional sources. From this, unit electricity cost for each of the system is calculated and compared among the systems.

III. LIFE CYCLE ASSESSMENT OF SOLAR PV AND CONVENTIONAL SOURCES

To compare the economic performance of grid tied solar PV systems with conventional power suppliers using fossil fuel sources over their complete life spans the ALCC for a grid tied PV system is calculated for a wide range of possible loads starting from 4 kWh going through 25 kWh. For the same range of loads the annualized LCC is also calculated for commercially available petrol generators of nine different ratings (0.8, 1.0, 1.2, 1.3, 2.0, 2.8, 4.0, 5.0 and 6.5kW) and a 4.2kW diesel generator. The generators are manufactured by Walton International limited. The objective of the study is to compare the different sets of data and determine the range of loads for which the grid tied PV system offers better economic returns over a petrol or diesel generator and also the criteria which makes the fossil fuel generators more cost efficient than their renewable energy counterpart.

TABLE II
LCC ASSESSMENT OF GRID-TIED SOLAR PV SYSTEM FOR 15KWH LOAD (1 US DOLLAR = 82 BDT)

Daily Load		15 kWh
Solar Panel Size		333W × 14 = 4662W
1) Capital Cost	Total Capital Cost	17,29,067.00
2) Fuel Cost	(No Fuel Required)	0.00
3) Recurring Maintenance Cost	Life Cycle Maintenance Cost	42,550.00
4) Non – recurring cost (Replacement cost)	Life Cycle Replacement Cost	270,521.00
Grand Total LCC for 20 years (=1+2+3+4)		20,42,138.00

To illustrate an example of LCC estimation for particular loads total number of sunshine hours is considered to be 5.24 hours for Bangladesh [14]. The following values of economic parameters are considered for analysis, period of analysis: 20 years, annualization factor: 8.51, discount rate: 10 %, inflation rate: 0%. The grid tied solar PV system has two major components: a solar panel for collecting solar power and an inverter for supplying AC loads. Assuming that the inverter efficiency to be 92% and solar PV (SPV) module losses to be of almost 80%. Table I provides the necessary calculations required for determining the size of solar panel and inverter in the grid tied solar PV system.

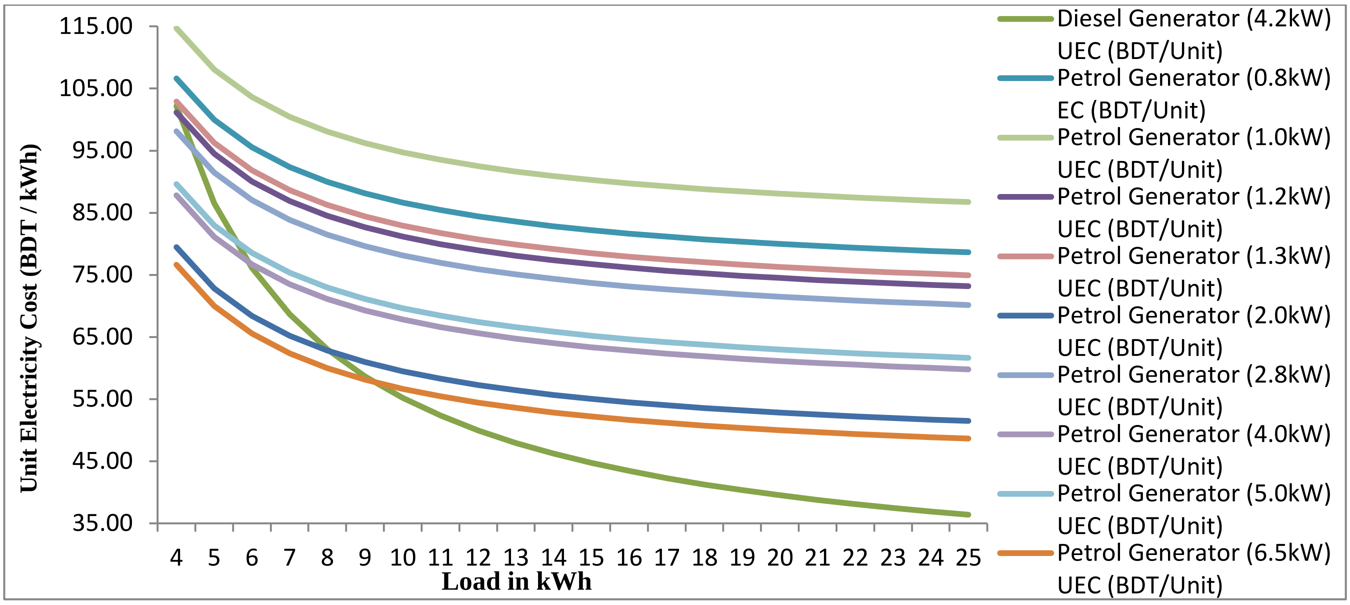

Fig. 3. Comparison of Unit Electricity Cost between Petrol Generators & Diesel Generator

In the next step the detailed calculation regarding Life Cycle Cost (LCC) assessment of the grid – tied solar PV system is presented in table II for a 15kWh daily load. After determining the LCC, the value of ALCC is determined using annualization factor that is calculated to be 8.51 for an analysis of 20 years duration. Then the unit electricity cost is calculated to make a comparison of grid tied solar PV system with petrol and diesel generators. Table III presents the calculation and comparison of unit electricity cost for four different loads, namely14kWh, 15kWh, 16kWh and 17kWh.

IV. Establishment of Breakeven Point in Cost Performance

The data indicate that the unit electricity cost of the grid tied solar PV system remains more or less the same from 4 kWh to 25 kWh. But as the load increases fossil fuel sources may become economically more viable when compared with their photovoltaic counterpart. This indicates the existence of a breakeven point within the permissible load range. To quantify this point we compare the unit electricity cost of solar PV, 0.8, 1.0, 1.2, 1.3,2, 2.8, 4, 5 and 6.5kW petrol generators, and 4.2kW diesel generator for 22 different load demands from 4 to 25 kWh and they are plotted in graphical form in fig. 1, fig. 2 and fig. 3. Fig. 1 manifest that for a 0.8, 1.0, 1.2, 1.3,2, 2.8, 4, 5 and 6.5kW petrol generators unit cost of solar PV is always lower for all load demands, so there is no breakeven point in these cases and solar PV is always the cheaper option. As for diesel generator (4.2 kW) and PV system the breakeven point is between 15 & 16 kWh as shown by fig. 2. But this would mean increased consumption of fossil fuels and higher emission of greenhouse gases. In fig. 3, it is indicated that, the diesel generator is more viable than the petrol generator after a certain amount of load. Here it is observable that, among the petrol generators, the UEC of 6.5kW petrol generator is always lower than that of other petrol generators. And it is also understandable that the 4.2kW diegel generator becomes cheaper than this petrol generator in terms of UEC after a certain amount of load. The crossover point is between 9 and 9.5kWh. Also, it is noticed that, for smaller loads, petrol generator is cheaper than diesel generator. But as load increases the situation reverses.

From LCC assessment solar PV has proved to be an economically better choice than conventional diesel (below 16kWh) and petrol generators (for all load ranges) for a developing country like Bangladesh for permissible domestic load applications. Moreover, from the point of view of environmental safety grid tied solar PV provides a positive impact by reducing greenhouse gas (CO_2) emission to the atmosphere [6].

TABLE III
Comparison Among Grid-Tied Solar PV System, Petrol Generator & Diesel Generator In Terms Of LCC, Annualized LCC & Unit Cost (Annualization Factor, AF = 8.51)

Daily Load (kWh)		Grid – tied Solar PV (3.0kW)	Diesel Generator (4.2kW)	Petrol Generator (6.5kW)
14.00	LCC	1901825.00	2010255.06	2297897.02
	ALCC	223481.20	236222.69	270023.15
	UEC	43.73	46.23	52.84
15.00	LCC	2042138.00	2084284.97	2432465.00
	ALCC	239969.20	244921.45	285836.07
	UEC	43.83	44.73	52.21
16.00	LCC	2182450.00	2158314.87	2567032.97
	ALCC	256457.10	253621.02	301649.00
	UEC	43.91	43.43	51.65
17.00	LCC	2322763.00	2232344.78	2701600.95
	ALCC	272945.10	262320.19	317461.92
	UEC	43.99	42.28	51.16

We know that, every litre of diesel fuel when burned produces 2.7 kg of carbon dioxide [15]. It has been calculated that, for the discussed 4.2kW diesel generator running for meeting up 16kWh demand, is consuming 2085.975 × 20 = 41,719.50 litre diesel in 20 years.

So, the amount of CO_2 produced in 20 years by the diesel generator is = 2.7 × 41,719.50 = 112,642.65 kg.

Also, for each litre of petrol fuel when burned produces 2.4 kg of carbon dioxide. It has been calculated that, the 6.5kW petrol generator running for meeting up 16kWh demand is consuming 2693.70 × 20 = 53,874 litre petrol in 20 years.

So, the amount of CO_2 produced in 20 years by the petrol generator is = 53,874 × 2.4 = 129,297.60 kg.

V. Limitations of Work

This work has been done by investigating all the diesel and petrol generators [16] of Walton Bd. which is a very renowned multinational company. But they currently have only one diesel generator and so the investigation has been made taking account with only one diesel generator. If Walton BD. Would have quite a few number of diesel generators as they have in case of petrol generators then the analysis would be more enriching.

VI. Conclusion

Life Cycle Cost Analysis evaluates the cost of a service delivered over the total life span of a project. The initial investment cost does not always suggest the true financial liability of a service throughout its lifetime. LCCA can be particularly convenient in such a case to make a long-term evaluation. Grid tied Solar PV units usually incur greater initial investment cost than petrol or diesel generators. But in the long run, the overall per unit energy production cost for fuel driven generators might not necessarily be better than the per unit electricity cost for grid tied solar PV and solar home system units. Using any grid connected systems; the produced excess electricity can be sold back to the grid. This adds some extra economic benefit to the consumers. The tariff in which the electricity can be sold back to the utility grid is called Feed – In – Tariff (FIT). The government can offer FIT to encourage the producers to initiate the installation of grid connected systems. They can offer to pay 80 – 90% of the retail price of per unit green electricity to the producers. In this way two things can be achieved. The shortage of electricity in the grid can be reduced and at the same time an extra source of income to the home – owners can be provided. Moreover, excessive harmonics, frequency and voltage mismatch problem between the electricity grid and solar generator have to be solved to make grid-tied solar systems feasible. This work's novelty lies in the discovery that the selection between renewable or conventional fuel driven power sources depends on the load demand and the power rating of the generators and grid tied solar PV systems perform better from both a commercial and an eco-friendly point of view for a developing country like Bangladesh where grid connection is available but cannot supply the full demand of mass people.

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